IMPLEMENTATION OF MIXED INTEGER LINEAR PROGRAMMING FOR HYDRO-THERMAL GENERATION SCHEDULING WITH RIVER AND RESERVOIR CONSTRAINTS

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To my lovely father, mother, and my country Iran

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ABSTRACT

A Short-term Hydro-thermal Scheduling (HTS) model based on Mixed Integer Linear Programming (MILP) is developed and presented in this thesis. For countries such as Malaysia that are close to the equator, high precipitation throughout the year replenishes existing water resources. The efficient scheduling of hydro and thermal units considering a large amount of water resources and river systems can significantly affect the total operation costs of the system. The HTS is a highly complex problem involving a large number of continuous and integer variables with nonlinearity and nonconvexity/nonconcavity characteristics in its objective function and constraints. A comprehensive MILP hydraulic model for unit-wise, and cascaded multi-chain reservoir system considering head variation effects has been developed. Incorporation of the detailed reservoir and river modelling with variable head makes the HTS problem even more complex with an additional number of integer/continuous variables as well as the constraints. A piecewise linear approximation is used to transform all nonlinearities into an equivalent linear model. Multi-thread computing is utilised to expedite the solution process of MILP Branch and Bound and Cut (BB & C) method using a certain number of concurrent threads. Obtained results show the successful implementation of the multi-chain river system modelling on several test cases including 69-unit, 132-unit and 287-unit. The proposed MILP-HTS algorithm is compared with a Lagrangian Relaxation (LR) algorithm that is currently employed by a real-world utility. Based on the similar input data, the MILP-HTS algorithm offers more optimal hydro-thermal generation strategy, taking into account a detailed hydraulic modelling. Based on the simulation results, the proposed MILP algorithm outperforms several other deterministic and heuristic techniques in terms of objective cost and execution time. Comparison with other equivalent MILP models over the same test conditions demonstrated that the proposed MILP model with the formulation presented in this thesis creates tighter relaxation (better cuts) in the BB & C solution process. This results in a cheaper objective value with a lesser computation time. Implementation of multi-thread computing improves the execution time performance for all case studies as compared with the serial computation time. Simulation results also suggest that the multi-threading can allow taking tighter optimality gap resulting in a more accurate solution (near-optimal) for large-scale problems in a moderate time, even with more detailed hydraulic modelling.

ABSTRAK

Satu model penjadualan jangka pendek Hidro-Termal (HTS) berasaskan pengaturcaraan campuran Integer Linear (MILP) telah dibangunkan dan dibentangkan di dalam tesis ini. Negara seperti Malaysia yang terletak berhampiran dengan khatulistiwa, kadar penurunan hujan yang tinggi sepanjang tahun telah meningkatkan sumber air yang ada. Penjadualan unit hidro dan termal yang cekap perlu mengambil kira jumlah sumber air yang besar dan juga sistem pengaliran sungai, jumlah keseluruhan kos operasi bagi sistem tersebut. HTS boleh menjejaskan dengan ketara yang melibatkan bilangan integer berterusan dan pelbagai yang banyak dengan ciri-ciri ketidaklelurus dan tidak boleh dikira dalam fungsi objektif dan kekangannya. Sebuah model hidraulik yang dilengkapi MILP untuk unit-cerdik dan sistem takungan berbilang-rangkaian lata dengan mengambil kira pelbagai turus perubahan telah dihasilkan. Penubuhan takungan secara terperinci dan pembentukan sungai dengan kesan perubahan turus menyebabkan masalah HTS bertambah rumit dengan bertambahnya bilangan integer/pembolehubah berterusan sekaligus kekangannya. Satu kaedah penghampiran titik-titik linear digunakan untuk mengubah ketidaklelurus kepada sebuah model lelurus yang seragam. Pengkomputeran Berbilang-Uliran digunakan untuk mempercepatkan proses penyelesaian kaedah MILP Cabang dan Had dan Potong (BB & C) dengan menggunakan jumlah serempak uliran yang tertentu. Keputusan yang diperolehi menunjukkan kejayaan dalam pelaksanaan model multi-rangkaian sistem sungai terhadap beberapa kes-kes ujian termasuk 69-unit, 132-unit dan 287-unit. Cadangan algoritma MILP-HTS dibandingkan dengan algoritma Santaian Lagrangean (LR), dimana merupakan kaedah yang digunakan oleh utiliti dunia sebenar. Berdasarkan data input yang sama, algoritma MILP-HTS menawarkan strategi untuk janakuasa hidro-termal yang lebih optimum, dengan mengambil kira model hidraulik yang terperinci. Berdasarkan keputusan simulasi, algoritma MILP yang dicadangkan melebihi prestasi beberapa kaedah berketentuan dan heuristik dari segi kos objektif dan masa pelaksanaan. Perbandingan dengan model MILP lain yang setaraf ke atas ujian yang sama menunjukkan bahawa model MILP yang dicadangkan berserta rumus yang dihuraikan di dalam tesis ini menghasilkan santaian yang lebih ketat (potongan yang lebih baik) bagi BB & C proses penyelesaian. Keputusan menunjukkan nilai objektif yang lebih murah dengan masa pengiraan yang lebih singkat. Pelaksanaan berbilang -uliran meningkatkan prestasi pelaksanaan masa untuk semua kajian kes berbanding dengan masa pengiraan bersiri. Keputusan simulasi juga mencadangkan bahawa berbilang-uliran boleh membenarkan pengambilan sela optimaliti yang lebih rapat, yang menyebabkan penyelesaian yang lebih tepat (menghampiri optimum) untuk masalah berskala besar dalam masa yang sederhana, walaupun dengan model hidraulik yang lebih terperinci.